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SCIENCE

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THE EVOLUTION OF HERBS

THE most ancient system of botanical classification which we know, first proposed by Aristotle and Theophrastus and even continued after the dawn of modern botany with the herbalists of the sixteenth century, divided all plants into three great and easily distinguishable groups, the trees, the shrubs and the herbs. As time went on, however, and as botanical knowledge grew more and more thorough, it became evident that any system of this sort, based simply on the habit of growth, not alone brought together many plants unrelated in almost every respect but separated others which clearly resembled one another in most of their characters. The old classification was therefore gradually abandoned and in its place grew up various systems in which an attempt was made to gather plants into more natural groups. Finally the theory of evolution, with its emphasis on actual genetic relationship as the basis of all sound classification, gave a great incentive to the building of hypothetical family trees and lines of descent in the vegetable kingdom. Almost all of these have been founded mainly on a comparative study of the various floral parts; and it is therefore with such structures that modern students of the morphology and taxonomy of plants have for the most part concerned themselves. The various types of growth habit, those most evident and striking of plant characters, so much emphasized by the earlier botanists, have consequently been largely negleant as being too variable and too dependant on a changing environment to be of much use in determining actual relationships.

But however valueless an inquiry which concerns these more conspicuous distinctions may be in tracing outlines of descent and determining the evolution of *flora*, it does provide us with important information as to the origin and development of plant forms, the evolution of *vegetation*. In many ways this knowledge is of more importance than the construction of family trees alone, for it is more often the growth habit of plants rather than their systematic position which is correlated with the climatic, geological and zoological factors in their environment. Indeed, to man himself the distinction between an herb and a tree is frequently of greater economic significance than that between two families of plants.

Investigations on this problem of the evolutionary history of growth forms among the higher plants has produced evidence from various sources that in comparatively recent geological time there has been a radical change in the character of much of the earth's vegetation, perhaps the most important one since the appearance of the angiosperms; a change produced by the origin and wide dispersal of those lowly but numerically abundant, quickly maturing and rapidly spreading plants, the herbs, in a vegetation which seems to have been previously composed almost entirely of trees and shrubs. Light has also been thrown on the factors which were responsible for the development of this new plant type and on the far-reaching changes which its introduction has caused in the history of plants, animals and man.

In any such problem of evolution as this we naturally turn first to a study of the fossil record. Of course the very earliest of land plants, if our present theories are correct, were delicate semi-aquatic species, probably resembling our modern liverworts, plants which from their

essentially herbaceous structure failed entirely of preservation. As to the development of these lowly forms into the vigorous and land-loving vascular plants which are now so completely dominant we know almost nothing, either from the geological record or from the occurrence of intermediate types. The luxuriant vegetation of the latter part of the Paleozoic, which gave us our first fossil plants, was composed of various ancient types of ferns, lycopods, horse-tails, cycad-ferns and gymnospermous seed plants. It is significant that although nearly all of these were either trees or stout woody forms, their representatives which have been able to survive to the present time have with few exceptions been reduced to such an herbaceous stature as characterizes our ground pines, horse-tails, quillworts and ferns to-day. Among the angiosperms, which occur as fossils only since the lower Cretaceous, a similar change seems to have occurred for nearly every one of the early fossil members of this great group were apparently woody plants. Of course it must be borne in mind, as in all such cases, that the geological record may not present us with a fair sample of an ancient flora; for the leaves of woody species would in general be much more favorable for preservation than the more delicate ones of herbaceous plants. As far as it goes, however, the geological evidence tends to indicate that among vascular plants, at least during the period covered by the earlier fossil record, woody forms were the dominant type of vegetation.

The labors of the botanical taxonomists have also provided us with a valuable clue as to the history of growth habits, particularly among the angiosperms. This now dominant race is generally agreed to have descended either from cycad-like types or from forms related to the conifers. Both

of these groups are to-day (and seem always to have been) composed entirely of woody plants. Furthermore, although opinion is still divided as to which of the living angiosperms are the most ancient, it is generally agreed that this distinction belongs either to the naked-flowered, catkin-bearing types grouped together as the Amentiferæ, or to the complete but simple-flowered Ranales. The former are almost exclusively trees or shrubs to-day and the latter are predominantly so, making it probable that the angiosperms at their inception were woody in character. Moreover, in cases where a particular genus, family or order contains both woody plants and herbs and where it is possible, on evidence from other sources, to determine which members are primitive and which are more recent, it is found in practically every instance that the woody forms are more ancient in type than the herbaceous ones. This is well illustrated in the Leguminosæ. Here the two most primitive sub-families, the Mimosæ and Cæsalpineæ, are almost exclusively woody, practically all the herbaceous forms being included in the obviously less ancient Papilionatæ. Evidence derived from a study of plant descent therefore also indicates the greater antiquity of the woody type of vegetation.

This conclusion again receives confirmation from a study of the anatomical structure of woody plants and herbs, for in the latter the various elements of the wood—the vessels, rays and parenchyma—are often widely different from their primitive condition as we see it in admittedly ancient types of vascular tissue, and have evidently undergone much modification and specialization.

The distribution of these various growth types over the globe to-day is of exceptional interest in providing us with evidence not only as to their relative antiquity but as to

the factors which have caused the change from one type to the other. The most striking fact which such an investigation establishes is the overwhelming predominance (in number of species) of herbs in temperate regions and of woody plants in the warmer parts of the earth. In Table I. are shown the numbers and percentages of herbaceous species in the floras¹ of nineteen typical regions.

TABLE I

	Total Species	Herba-ceous Species	Per Cent. Herbs
Ellesmereland.....	76	71	93
The Faroes.....	164	150	91
Switzerland.....	1,899	1,726	91
Iceland.....	221	200	90
Great Britain.....	927	821	89
Rocky Mountains.....	2,206	1,910	87
Russian Empire.....	14,704	12,588	86
Germany.....	1,117	947	85
Spain	4,481	3,554	79
Northern United States.....	2,662	2,089	78
Japan.....	3,257	1,861	57
Florida Keys.....	415	225	54
Tropical Africa.....	8,577	3,560	42
Hongkong.....	728	293	40
Ceylon	1,793	670	37
British West Indies.....	2,249	675	30
Java.....	3,188	867	27
Brazil.....	15,981	4,092	26
Lowlands of the Amazon Valley.....	2,209	265	12

It will be noted that in the tropics only about ten to forty per cent. of the species are herbaceous, but that as we go into cooler regions the proportion of such plants greatly increases until in arctic and alpine areas they constitute ninety per cent. or more of the flora. Of course these figures do not mean that the *vegetation* of temperate regions is mainly herbaceous. Forests, indeed, are well developed there, but they are composed of only a few hardy families of trees; whereas in the tropics almost every family has numerous woody representatives. The tropical floras analyzed included in almost all cases many plants

¹ In these analyses dicotyledonous plants alone are considered.

from cool upland or mountain regions, where herbs are commoner than in lowlands, and the herbaceous percentage is accordingly higher. In the lowland tropical forest, however, as is shown in the selected figures for the Amazon Valley only, herbaceous species are extremely few.

The most important limiting factor to the spread of tropical vegetation seems to be the occurrence, even for a very short time during the year, of temperatures near the freezing point. As to just what the climate was like under which the angiosperms first appeared we are not altogether certain, but freezing temperatures seem for the most part to have been quite absent. We may reasonably infer that conditions then favored an overwhelming development of trees and shrubs such as we see in winterless regions of the earth to-day.

An examination of those floras which are believed to be very ancient and to be composed of plant types which have elsewhere disappeared, is of especial interest for our problem. The organic life of certain isolated oceanic islands, in particular, is generally recognized as giving us a rough idea of the fauna and flora which existed over wider areas in ancient times; and the "endemic" animals and plants—those which are peculiar to the region and are found nowhere else, and which in such oceanic islands constitute a large proportion of the species—are regarded as still more ancient than the non-endemic element; for they must either have had a long evolutionary history in the region or must be remnants of older types which have elsewhere become extinct. Table II. shows the percentage of herbs among the non-endemic species (most recent element); the endemic species of non-endemic genera (intermediate element); and the species of the endemic genera (most ancient element) in certain of these insular floras.

TABLE II

	Recent Element, Per Cent. Herbs	Inter- mediate Element, Per Cent. Herbs	Ancient Element, Per Cent. Herbs
Hawaii (582 species).....	76	21	9
Fiji (563 species).....	26	.2	0
Juan Fernandez (89 species)	94	27	0
St. Helena (41 species).....	73	32	0
Socotra (517 species).....	85	26	9
Mauritius and the Seychelles (587 species)	59	16	5

It is evident that the youngest element is predominantly herbaceous, the intermediate one less so, and the oldest almost entirely woody. In fact, the great majority of herbs in these insular floras apparently arrived such a short time ago that they have not yet developed into endemic types, but are still identical with species in other regions. This is the more noteworthy since herbs, because of the brevity of their life-cycles and their consequent multiplication of generations, tend to change more rapidly than woody plants. The vegetation of these ancient islands thus seems to have been, in times not very remote, even more devoid of herbs than it is at present. In such islands as Bermuda and the Azores, on the contrary, where from the almost complete absence of endemic species we have reason to believe that the flora is not ancient, the percentage of herbs is fully as high as in continental areas of similar climate.

The larger land masses of the south temperate zone—Australia, New Zealand, southern South America and South Africa—which have also been isolated in a greater or less extent from the continental areas of the northern hemisphere, resemble ancient oceanic islands to a certain degree in the composition of their vegetation. In Table III. are shown the percentages of herbs among the species of the non-endemic genera (recent) and among the endemic genera (ancient) in the floras of these regions.

TABLE III

	Recent Genera, % Herbs	Ancient Genera, % Herbs
Australia (5,711 species).....	62	17
New Zealand (1,026 species).....	81	20
Southern South America (1,587 species).....	87	48
South Africa (7,984 species).....	58	30

Here again, though not to as marked a degree as in insular floras, the more ancient element is predominantly woody and the more recent predominantly herbaceous.

It is noteworthy that there are many species of plants in the ancient insular floras which are identical or nearly identical with species on widely distant oceanic islands or on ancient continental areas, a fact which strengthens our belief that the vegetation of these regions is a remnant of one which was formerly much more widely spread.

If the herbaceous element in the vegetation of such isolated regions as we have described is entirely or in great part of recent arrival, we naturally look for its seat of origin to the extensive land areas of the north temperate zone where herbs to-day reach such high development, and where so many new types of animals and plants have had their birthplace. Even here there is evidence that the woody element in the vegetation was at one time much more diversified and prominent than at present, for very many genera and families of trees and shrubs are found here as fossils from the Cretaceous and Tertiary which are absent from the living floras. This is particularly true of Europe, where there are to-day so few species of woody plants.

These facts—that woody plants are more ancient than herbs as shown by evidence from fossils, from natural relationships and from anatomy; that herbs are now dominant and woody plants few in species in regions subject to low winter temperatures, and *vice versa*; that regions which have

been isolated from the north temperate land mass possess few herbs in the ancient portion of their floras, and that the northern continents supported at no very ancient date a much more varied woody vegetation than at present—all suggest the conclusion that a large portion, at least, of our modern herbaceous vegetation originated in the north temperate zone in response to the progressive refrigeration of climate which we know to have taken place there during the Tertiary.

The great advantages conferred by the possession of an herbaceous habit of growth in a region subject to low winter temperatures are obvious, for such plants are able to complete their cycles and to mature seed in the warm summer months and can then survive the cold of winter in the form of resistant seeds or by hibernating underground. Only the hardier types can maintain permanent aerial stems under these conditions. The more delicate woody families have either been exterminated outright in temperate regions or have survived only by assuming an herbaceous habit and thus flourishing in that part of the year which is free from frost. As might be expected if low temperature has indeed been the determining factor in the development of herbs, most of those families which are well able to survive cold as trees or shrubs and which form the bulk of the woody vegetation of the north temperate zone—the willows, birches, oaks, beeches, walnuts, hickories, wax myrtles, elms, hollies, maples, heaths, buckthorns, lindens, planes, sumachs, cornels, and viburnums—are families which are almost entirely without herbaceous members. Being hardy, they have not been forced to adopt the herbaceous habit.

As to the details of this change in growth habit we can not of course be sure, but in those forms which it did not kill outright

the increasing cold probably effected a gradual reduction in size and an attendant shortening of the time necessary to reach maturity, until very dwarf forms were produced which were able to develop from seed to seed in a year or two, and which could be killed back to the ground every winter—in short, perennial herbs. The herbaceous vegetation in arctic and alpine regions to-day is still composed almost entirely of such plants. The annual herb seems to have developed from this primitive type under more favorable environments, where a plant growing from seed, and thus without a subterranean food reservoir to give it a rapid start, could become large enough in a single season to reproduce itself.

The northern vegetation thus developed proved extremely hardy and aggressive, and was able not only to overspread the great continental area of the north temperate zone but to invade as well the tropics and even the Antipodes. The presence of a large number of typically northern genera of plants in Australasia, southern South America and South Africa, often separated from their related forms by the whole width of the tropics, has long been recognized as one of the most fascinating problems of plant distribution. It is important to note that this invasion of northern plants (nearly 200 genera are known) which has been so successful in penetrating far southern regions and which displays so well the "wonderful aggressive and colonizing power of the Scandinavian flora" to which Wallace and others have called attention, has in reality been an invasion of *herbs*, for almost none of the northern trees and shrubs have participated in it.

Herbaceous plants have also been developed in the south temperate zone apparently in response to the refrigeration of climate there in the late Tertiary. Ant-

arctic herbs were doubtless among the very last plants to leave the polar continent as the glaciers advanced. They are still almost all alpine or cold-loving perennials and have as yet failed to give rise to the aggressive lowland annual type.

Refrigeration of climate was doubtless not the only factor in the development of an herbaceous vegetation. A large body of such plants seem to have originated in arid regions, where they spring up rapidly and produce seed during a rainy season, thus bearing precisely the same relation to extremes of moisture that arctic or alpine herbs do to extremes of temperature. The assumption of a rapidly climbing habit, especially in the tropics, has also resulted in the development of an herbaceous type of stem in such families as the melons, milk-weeds and passion-flowers.

But whatever the cause of their origin, herbs have proved themselves an exceedingly versatile and aggressive type of vegetation under almost all climatic conditions. The reasons for this dominance of the herb are not far to seek. It is able not only to thrive in cold and arid regions but, from the brevity of its life-cycle, can take advantage of temporarily favorable conditions of any sort. Its evident and great superiority over woody plants in rapidity of dispersal and ability to invade new areas quickly is due in large measure to the fact that its interval from seed to seed, instead of being many years, is only a few months. Every seed may itself become a center of dispersal in a season's time. The amount of seed produced, too, in proportion to the bulk of plant body which has to be developed is far greater among herbs than among woody forms. Owing to the rapid multiplication of their generations herbs are capable of more rapid evolutionary change than are trees or shrubs and hence are able to adjust themselves more rapidly to new conditions.

With these various advantages it is not surprising that the herbaceous habit to-day characterizes not only great numbers of the commonest and most dominant native plant species in all parts of the world but also that huge array of hardy and ubiquitous plants which we know as weeds.

This radical change in the growth habit of many plants from a woody to an herbaceous type which has taken place for the most part since the beginning of Tertiary time cannot have failed to exert an important influence on animal life. It may well be connected with the rapid evolution of mammals which we know to have occurred after the early Tertiary. To quote from Chamberlin and Salisbury:

The earliest Eocene mammals were much more primitive and obscurely differentiated than even those of the middle Eocene, and this rapid backward convergence seems to point to some set of conditions which caused an exceptionally rapid development of the great class at this stage, whatever their previous history had been. The coming into a new domain of rich and varied conditions, whether by immigration or indigenous development, may be safely included among those conditions.

Is it not reasonable to suppose that the appearance of a great body of herbaceous vegetation just at this time was one of these conditions? This would affect directly the development of all herbivorous types and indirectly of many others. In the evolution of the tooth of the herbivora, indeed, we can trace the change from a sharply cusped type, suitable for chewing tough leaves and twigs, to the modern flat condition which is capable of dealing only with the softer herbaceous tissues.

The development of herbs was also apparently of some importance in the evolution of bird life, for the appearance of an immense new food supply produced by this terrestrial, seed-bearing vegetation, must certainly have led to the much greater abundance of such ground-loving types as

the finches and others, and may well have been responsible for their origin. So closely are plants and insects related, too, that a radical change in the one can not have been without effect on the other.

Far more important, however, is the part which the herb has played in the development of human civilization. Primitive man seems to have been mainly arboreal in his habits, or at least primarily a forest dweller, and the wood, bark and fruit of trees and shrubs were of supreme importance to him as sources of shelter, fuel, implements, clothing and food. One of his first steps from this barbarism toward civilization was to enter the open and begin the practise of agriculture. Those plants which most commended themselves to the earliest tillers of the soil were probably not the slow-growing trees and shrubs but rather the herbs, since the rapidity with which they grow and reach maturity makes possible their culture even among such roving tribes as were our North American Indians. Only as man acquired a settled place of abode and a more permanent form of society could he begin the culture of woody plants in orchard and vineyard; and it is only in very recent times that agriculture has extended beyond these fruit-bearing trees and shrubs and, in the form of forestry, has begun to treat timber trees themselves as a crop to be cultivated.

The marked superiority of the herb in ease of agricultural manipulation, together with the wide variety of uses of root, stem, leaf and fruit, have given it an increasingly high place in man's favor. To be sure, trees and shrubs provide us with timber, fuel, paper, rubber, fruits, nuts, coffee, tea, cocoa, vineyard products, turpentine and many drugs and items of lesser consequence. Among herbaceous products, however, are found all the cereals and vegetables, together with sugar, tobacco, most

of the fibers, certain of the fruits, and very many other valuable commodities. In addition to all this, the animal industries, which are the sources of milk, meat, leather and wool, are dependent entirely upon herbs. The dominance of such plants in agriculture is shown by the fact that in the United States they contribute 96 per cent. of the value of the products of this fundamental industry. Without herbs, the feeding and clothing of our great populations to-day would be quite impossible, and though it is conceivable that with the advance of science civilized man might possibly dispense with woody plants, in the absence of herbs he would perforce revert almost to savagery again. Human society is essentially an herbaceous product.

Although a study of the evolution of growth-habits may not provide much information as to the natural relationships of the higher plants, as we remarked at the outset, it does nevertheless introduce us to a momentous chapter in the history of the vegetable kingdom, for these lowly forms have not only possessed the earth and determined the character of many types of animal life, but to their indispensable aid man himself really owes his career as a civilized being. EDMUND W. SINNOTT

CONNECTICUT AGRICULTURAL COLLEGE

CONTRIBUTIONS OF CHEMISTRY TO THE SCIENCE AND ART OF MEDICINE¹

AT the last two meetings of this Society the general sessions have been devoted chiefly to symposia upon the contributions of the chemist to the varied phases of our American industrial development. Such emphasis is both timely and well merited. But I am impressed that this record of achievement should not be

¹ Presented to the Division of Biological Chemistry of the American Chemical Society at the spring meeting at Champaign, Ill., April 17-21, 1916.

closed without some consideration of the contributions of chemistry to the science and useful art of medicine. The opportunity seems likewise propitious for some suggestions as to means by which future contributions in this direction may be increased in number and in value.

The *science* of medicine consists in the knowledge of the normal processes of the human body (physiology) and of the nature and causes of abnormal deviations (pathology). The *art* of medicine includes the prevention of such deviations (hygiene), their identification (diagnosis) and their correction or alleviation by therapeutic or surgical treatment. For its present state of development each of these branches owes much to the contributions of chemistry.

Since Lavoisier's demonstration of the identity of respiration with combustion the chemist has gone step by step with the physiologist in elucidating the normal operations of the first internal combustion engine. Chemical structure of inanimate carbohydrates, lipins and proteins sheds reflected light upon the reactions and structure of living protoplasm. Colloidal chemistry, catalysis and the laws of chemical dynamics furnish all that we know of those servants of the cells, the enzymes. A new constituent of the blood is recognized to-day and to-morrow we have a new theory of metabolism. Thermochemistry is the foundation of nutrition and dietetics. The occultism of biogenesis, growth and the internal secretions is giving way before the calorimeter and the differential equation. In a word, the whole datum of physiological chemistry is a contribution to physiology and hence to the science of medicine; that much of it yet lacks practical application is no discredit to the contributor.

So much yet remains to be done in the field of chemical pathology that we are sometimes inclined to disparage past achievements. But these are not inconsiderable. In edema, concretions, diabetes and other conditions of acidosis, pathological variations in metabolism in fever, and in numerous other directions substantial gains have been recorded. Uric acid